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# A Five-Year Performance Evaluation of Environment Canada's Operational Regional Air Quality Deterministic Prediction System

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# Talk Outline

- **Model Characteristics and Outputs**
- **AQ Measurement Data Characteristics**
- **AQ Measurement Data “Cleansing”**
- **Selected 5-Year Evaluation Results for 2010-2014 Period**
- **Summary and Conclusions**



# GEM-MACH vs. GEM-MACH15 vs. GEM-MACH10

- GEM-MACH is a multi-scale chemical weather forecast model comprised of dynamics, physics, and *in-line* chemistry modules
- GEM-MACH15 is a particular configuration of GEM-MACH chosen for operational AQ forecasting; its key characteristics include:
  - introduced as operational forecast model in Nov. 2009
  - limited-area-model (LAM) grid configuration for North America
  - 15-km horizontal grid spacing, 58 vertical levels to 0.1 hPa
  - 2-bin sectional representation of PM size distribution (i.e., 0-2.5 and 2.5-10  $\mu\text{m}$ ) with 9 chemical components
  - output species include hourly fields of  $\text{O}_3$ ,  $\text{NO}_2$ , and  $\text{PM}_{2.5}$  needed for Air Quality Health Index forecasts
- GEM-MACH10 is the same as GEM-MACH15 except with 10-km horizontal grid spacing and 80 vertical levels to 0.1 hPa
  - introduced as operational forecast model in Oct. 2012

# Operational GEM-MACH Chronology: 2009-14

## (Changes to Piloting Model, Code, Grid, Emissions)

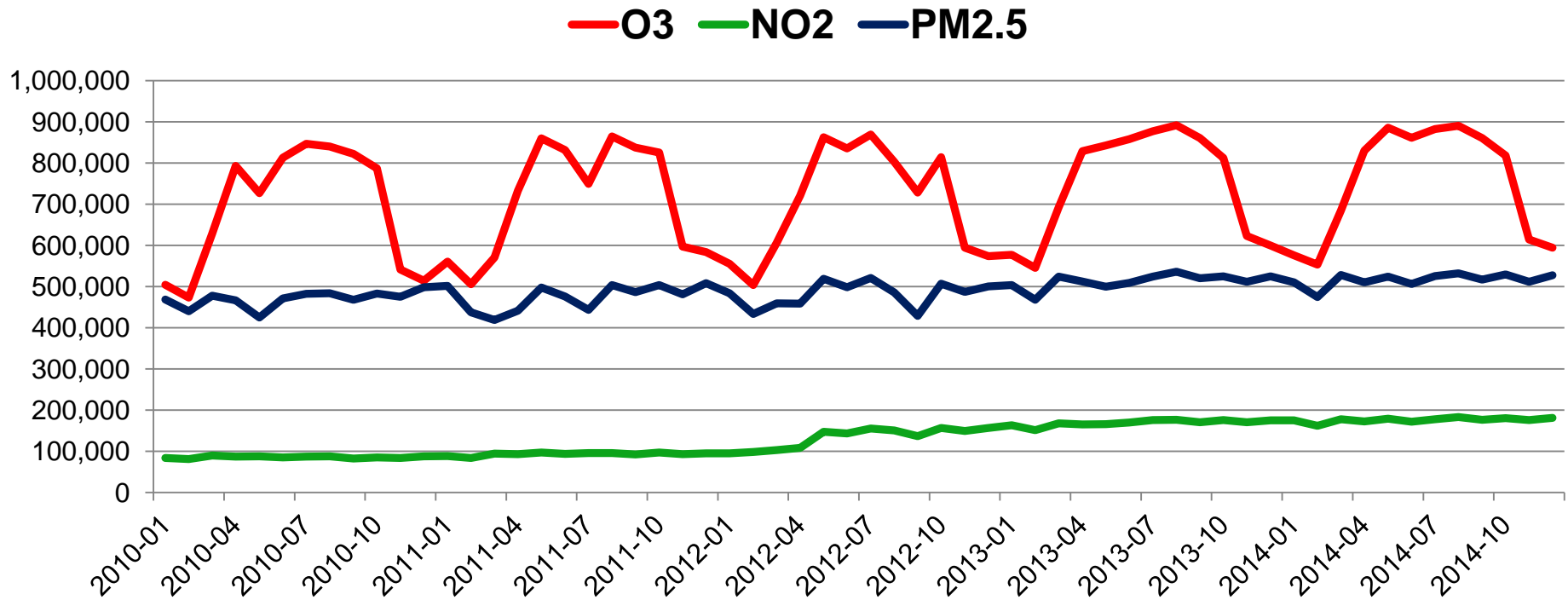
1. Nov. 2009: GEM-MACH15 becomes operational
2. Mar. 2010: New emissions files introduced with modified primary PM<sub>2.5</sub> spatial distribution in Canada
3. Oct. 2010: Piloting model: GEM15 → GEM-LAM15
4. Oct. 2011: New code version, new emissions (SET0)
5. Oct. 2012: GEM-MACH10 & GEM-LAM10 become operational, new emissions (SET1)
6. Nov. 2012: Reversion to SET0 emissions
7. Feb. 2013: New code version, 3 bug fixes
8. Nov. 2014: New GEM code, new GEM-LAM10

# AQ Measurement Data Characteristics (1)

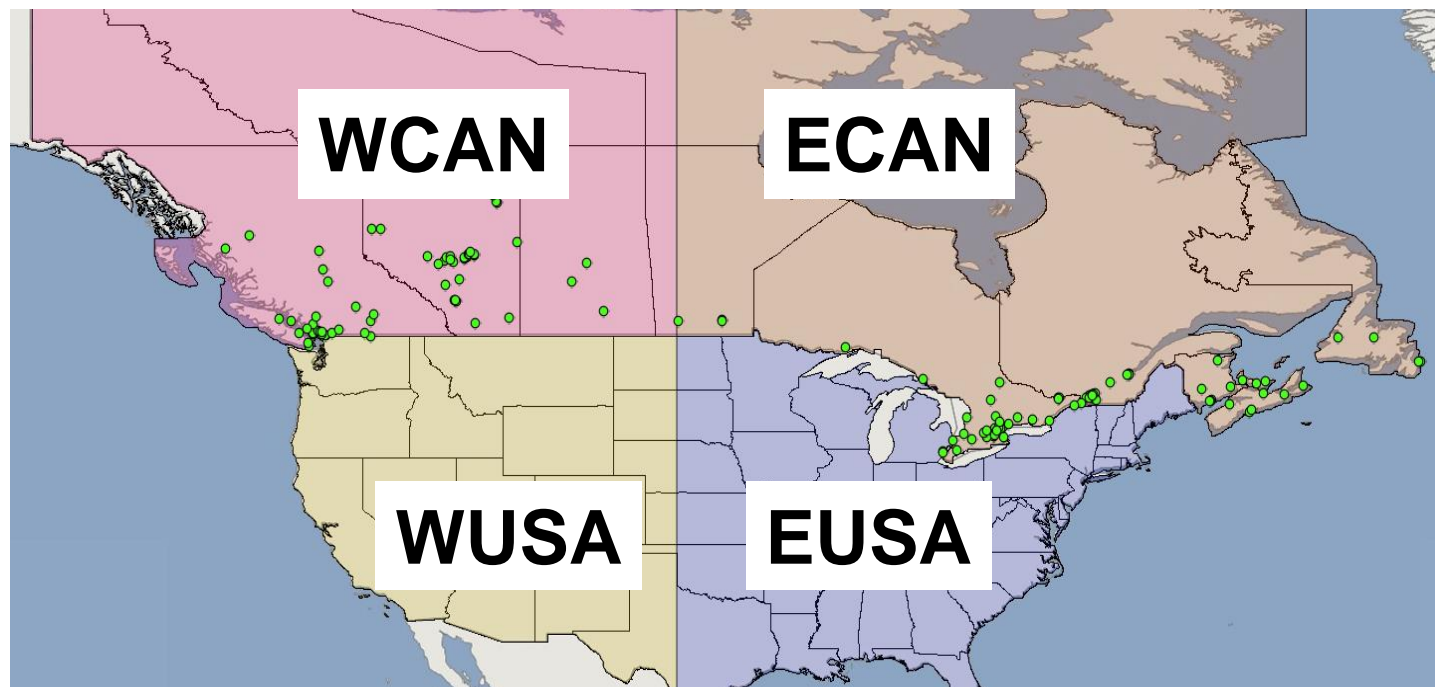
- Used archived near-real-time hourly  $O_3$ ,  $PM_{2.5}$ , and  $NO_2$  Canadian data from National Air Pollutant Surveillance (NAPS) network stations and hourly  $O_3$ ,  $PM_{2.5}$ , and  $NO_2$  U.S. data from AIRNow for 5-year period from 2010-14 (extracted as data pairs with accompanying model values from EC VAQUM evaluation system)
- Many U.S.  $O_3$  monitors only operate during the “ozone season”
- AIRNow started transmitting U.S.  $NO_2$  mmts in mid 2012
- AIRNow performs some quality control (QC) and some QC is performed on Canadian data upon receipt at CMC Dorval
- Included both urban and rural stations initially

# AQ Measurement Data Characteristics: Time Variation of Number of Observations

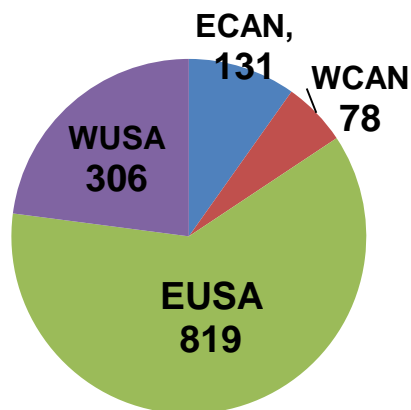
## Number of Observations Per Month, 2010-14



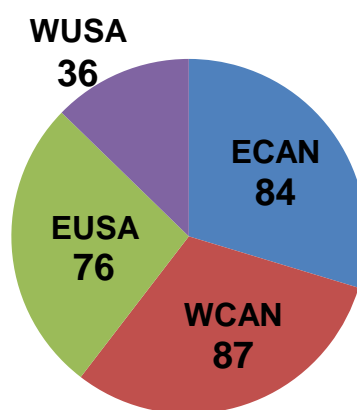
# AQ Data Characteristics: Station Distribution



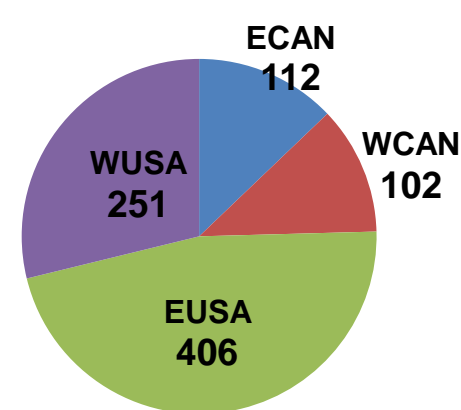
**O<sub>3</sub> (1,334 stns)**



**NO<sub>2</sub> (283 stns)**

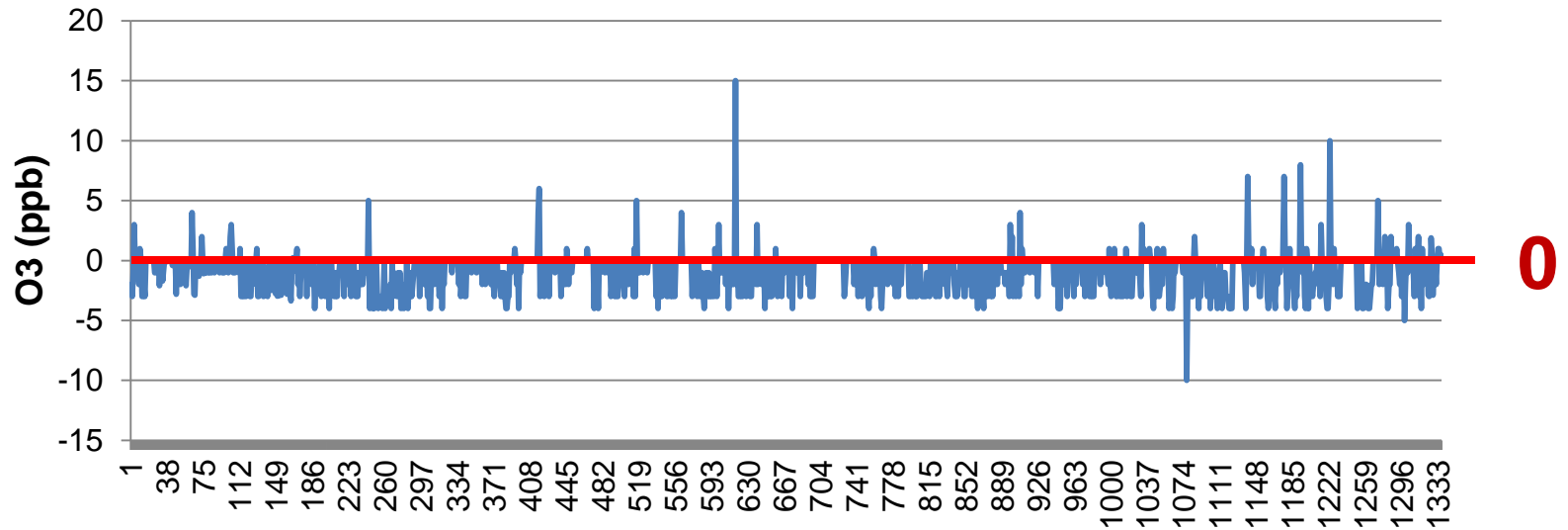


**PM<sub>2.5</sub> (871 stns)**

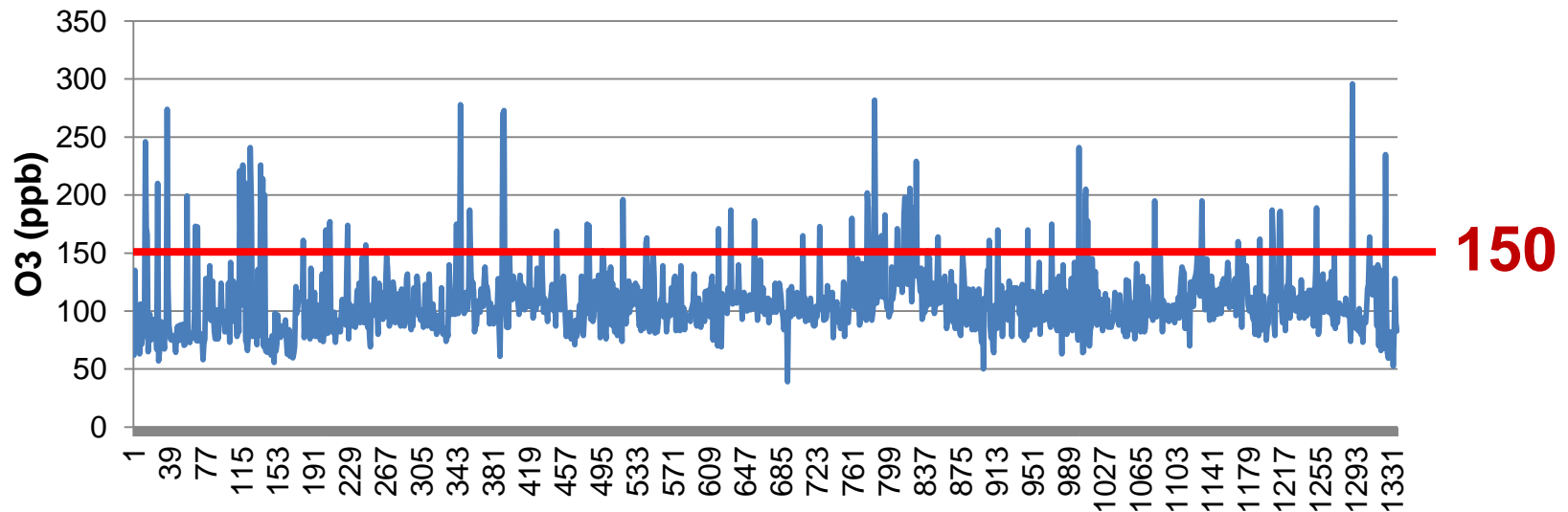


# AQ Measurement Data Characteristics: O<sub>3</sub> Extrema

## O<sub>3</sub> Observed Minimum by Station, 2010-2014



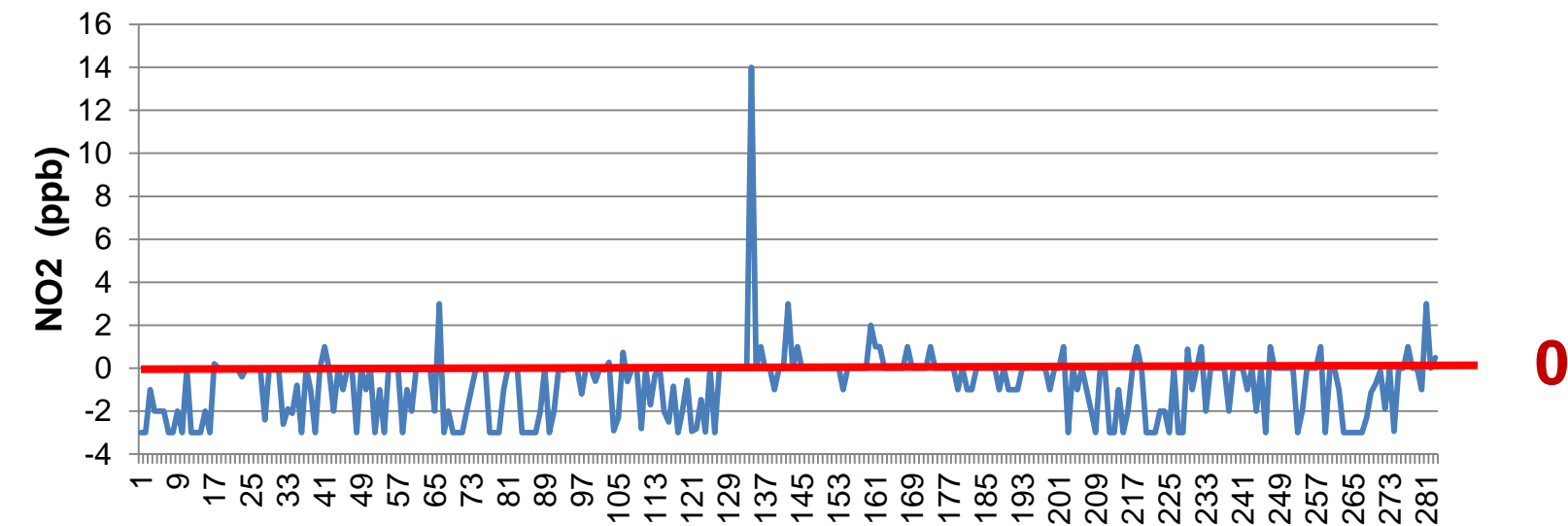
## O<sub>3</sub> Observed Maximum by Station, 2010-2014



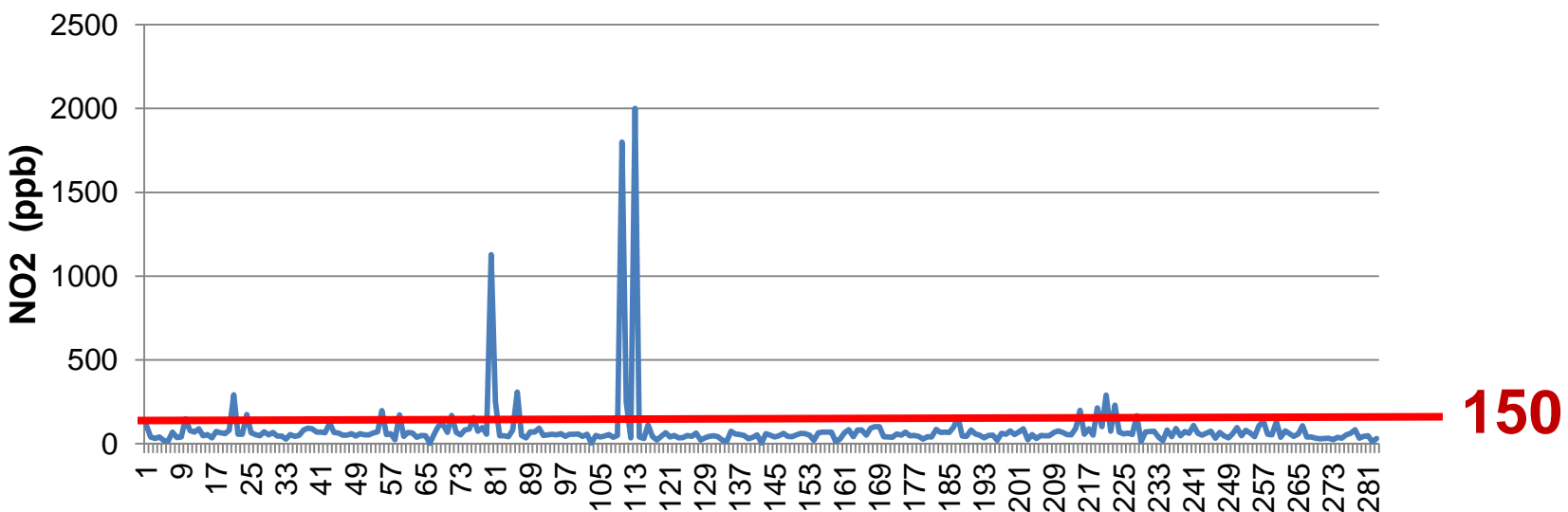


# AQ Measurement Data Characteristics: NO<sub>2</sub> Extrema

NO<sub>2</sub> Observed Minimum by Station, 2010-2014

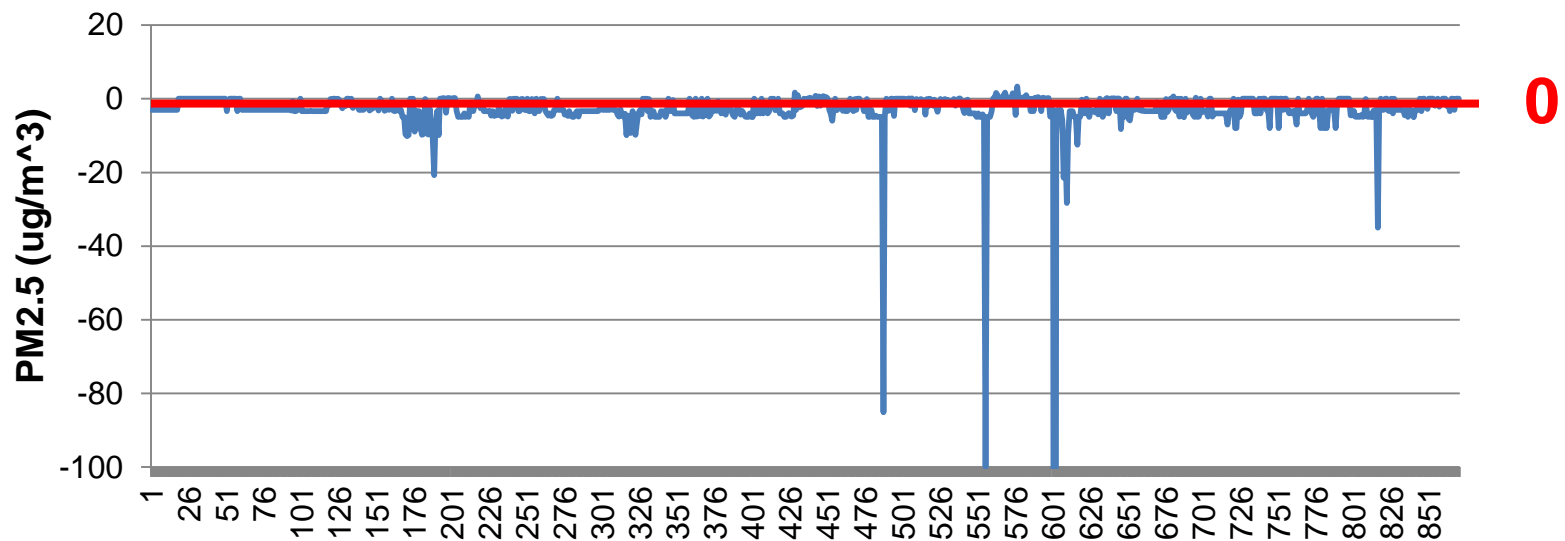


NO<sub>2</sub> Observed Maximum by Station, 2010-2014

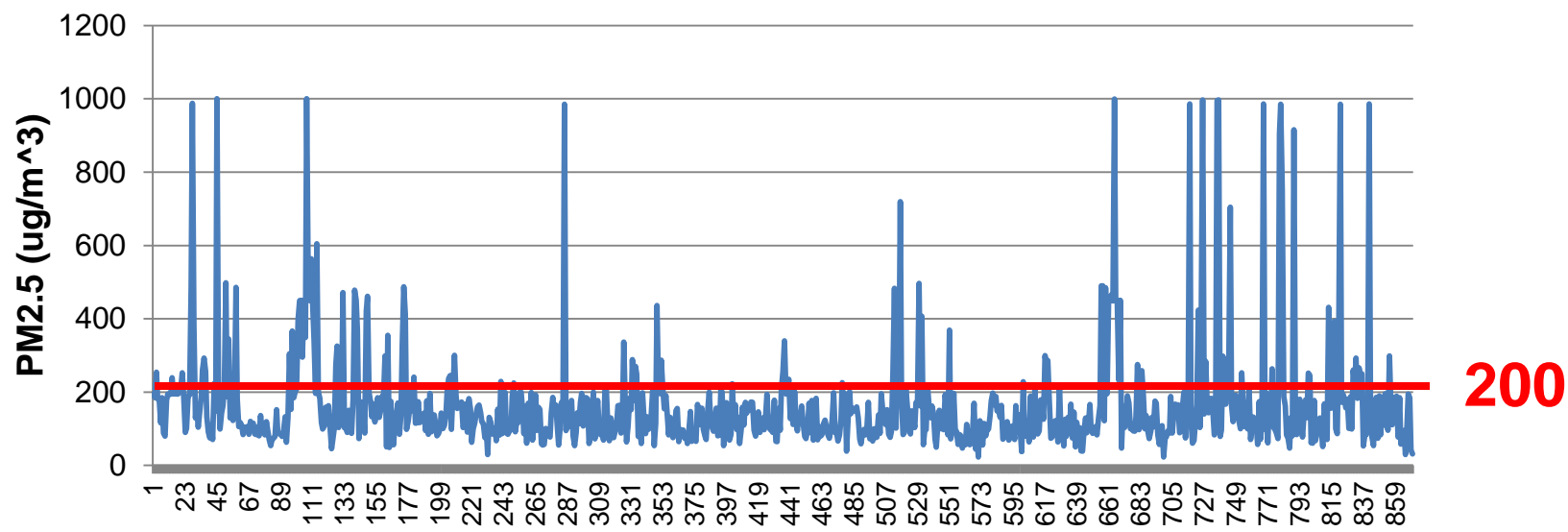


# AQ Measurement Data Characteristics: PM<sub>2.5</sub> Extrema

PM<sub>2.5</sub> Observed Minimum by Station, 2010-2014



PM<sub>2.5</sub> Observed Maximum by Station, 2010-2014



# AQ Measurement Data “Cleansing” (1)

- Further data “cleansing” is required before AQ measurement data are used to evaluate model performance
- **Step 1: Data completeness** (representativeness data filter based on long-term availability of valid hourly measurements)
  - $O_3$  option 1 – 75% completeness over 5 years
  - $O_3$  option 2 – 75% completeness over 5  $O_3$  seasons
  - $NO_2$  option 1 – 75% completeness over 5 years
  - $NO_2$  option 2 – 75% completeness over 2 years (2013-14)
  - $PM_{2.5}$  option 1 – 75% completeness over 5 years

If a station does not meet this check, **all** of its data pairs are removed from the 5-year evaluation data set

# AQ Measurement Data “Cleansing” (2)

- **Step 2: Daily range check** (“non-flatness” data filter to avoid constant measurements throughout a day)
  - $O_3$  – range > 1 ppbv per 24 hours
  - $NO_2$  – range > 0 ppbv per 24 hours
  - $PM_{2.5}$  – range > 0.1  $\mu g\ m^{-3}$  per 24 hours

If a station reports constant or near-constant measurements for 24 hours, all 24 data pairs are excluded from the 5-year evaluation data set

The  $NO_2$  range check is very “tight” because some remote stations can measure very low  $NO_2$  concentrations for extended periods

# AQ Measurement Data “Cleansing” (3)

- **Step 3: Exceedance thresholds** (extrema data filter)
  - $O_3$  – exclude values  $< 0$  ppbv or  $> 150$  ppbv
  - $NO_2$  – exclude values  $< 0$  ppbv or  $> 150$  ppbv
  - $PM_{2.5}$  – exclude values  $< 0$   $\mu g\ m^{-3}$  or  $> 200$   $\mu g\ m^{-3}$

Such values are rare and most are suspect, but they can have a material impact on statistical metrics

Elevated  $PM_{2.5}$  values can occur due to both wildfires and dust storms, but the current RAQDPS does not consider either emissions source

# Impact of Data Completeness Check on Number of Stations Used in Evaluation

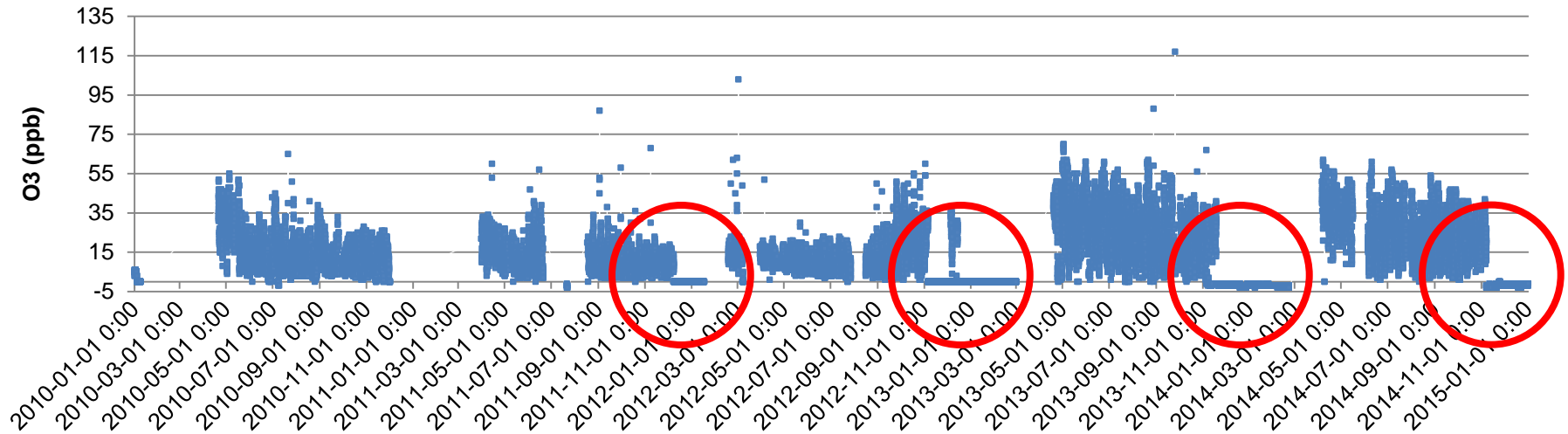
Species	All Stns	Option 1	Option 2
O <sub>3</sub>	1,334	753	1,184
NO <sub>2</sub>	283	131	238
PM <sub>2.5</sub>	871	623	N/A

# Impact of Range and Threshold Checks on Number of Data Pairs Used in Evaluation for Five-Year 75% Data Completeness Data Set

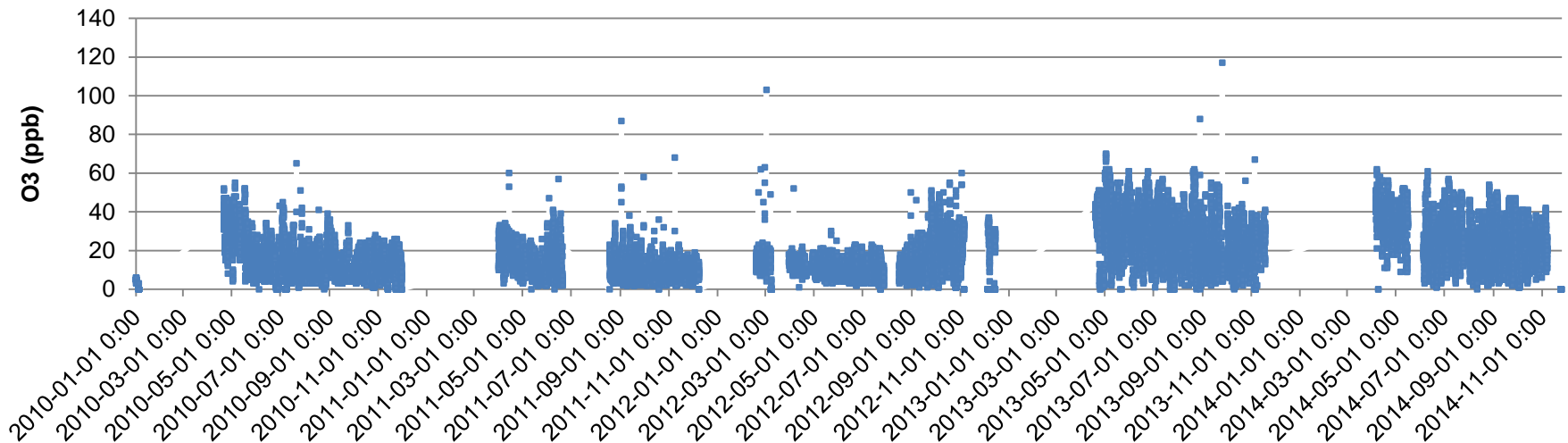
Species	Range Check	Threshold Check	Both Checks
O <sub>3</sub>	-0.1813%	-0.0007%	-0.1820%
NO <sub>2</sub>	-1.6737%	-0.0012%	-1.6749%
PM <sub>2.5</sub>	-0.2031%	-0.0050%	-0.2081%

# Example of Impact of Data Filtering on a Single-Station 5-Year O<sub>3</sub> Time Series

**2010-14 O<sub>3</sub> Time Series at a U.S. Station *Before* Data Filtering**

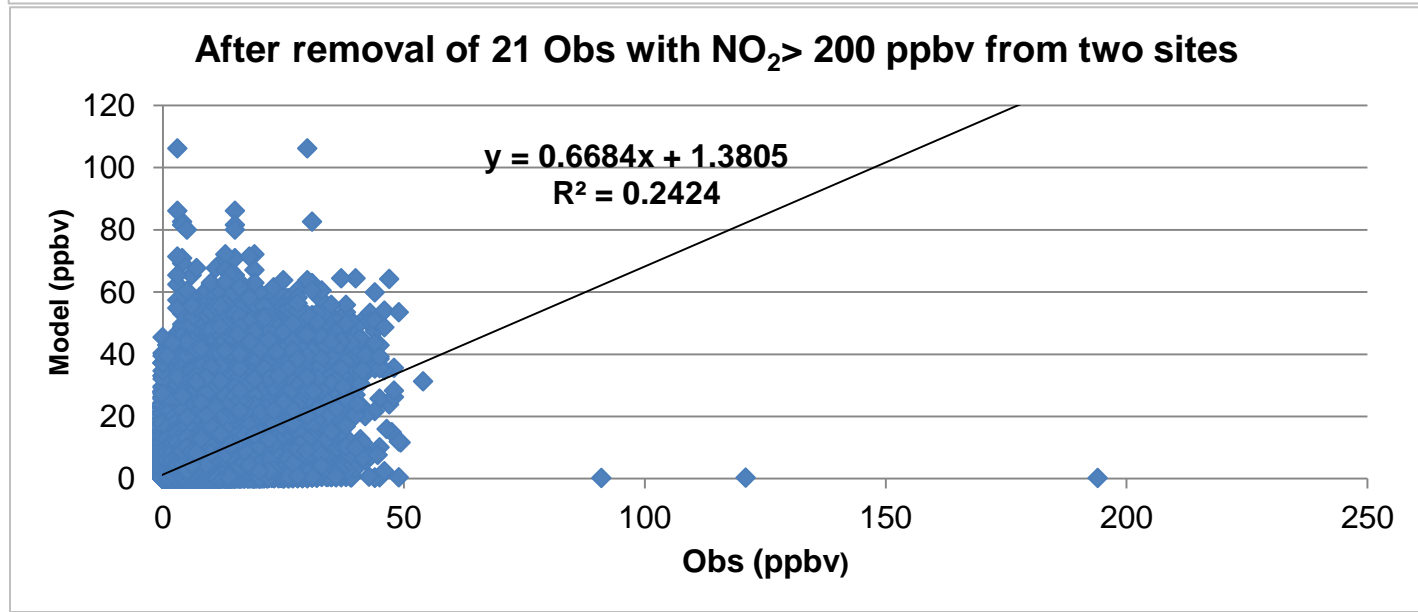
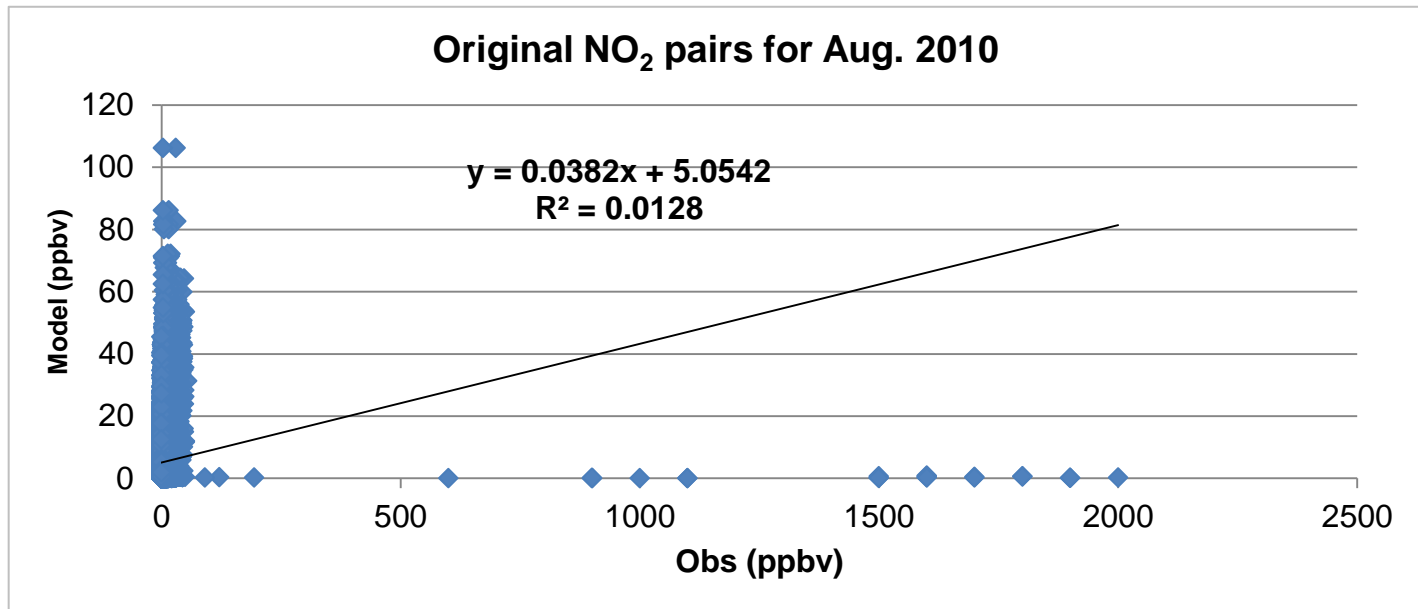


**2010-14 O<sub>3</sub> Time Series at a U.S. Station *After* Data Filtering**





# Impact on Statistics of Removal of 21 NO<sub>2</sub> Observations > 200 ppbv Out of 87,869 Observations



03 - R



# Correlation Coefficient R for Hourly O<sub>3</sub>, 2010-14 Period, All 75%-Data-Complete Stations

0.80

0.75

0.70

0.65

0.60

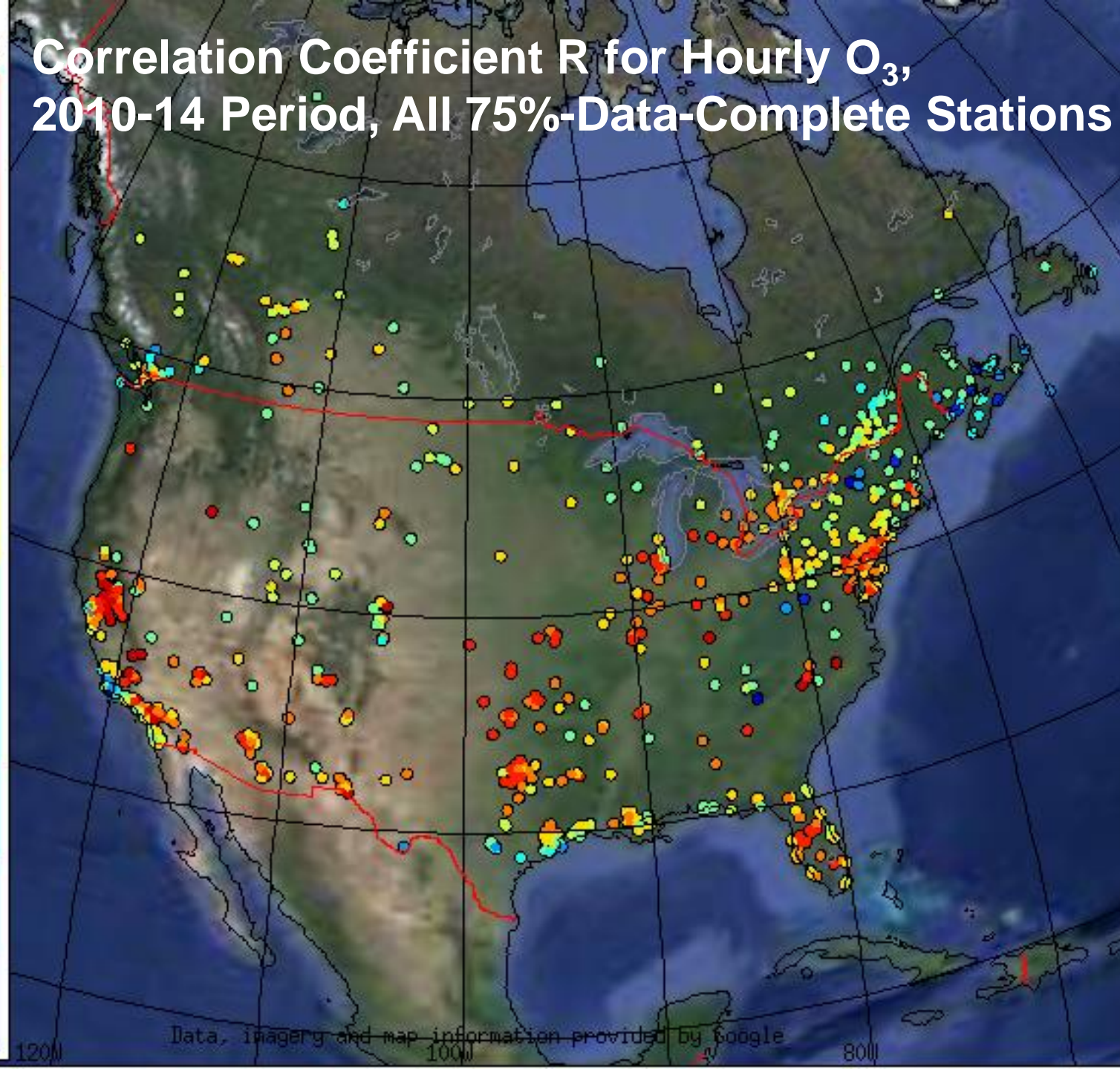
0.50

0.45

0.40

0.35

0.30



Data, imagery and map information provided by Google



NO2 - R



# Correlation Coefficient R for Hourly NO<sub>2</sub>, 2010-14 Period, All 75%-Data-Complete Stations

0.75

0.70

0.65

0.60

0.50

0.45

0.40

0.35

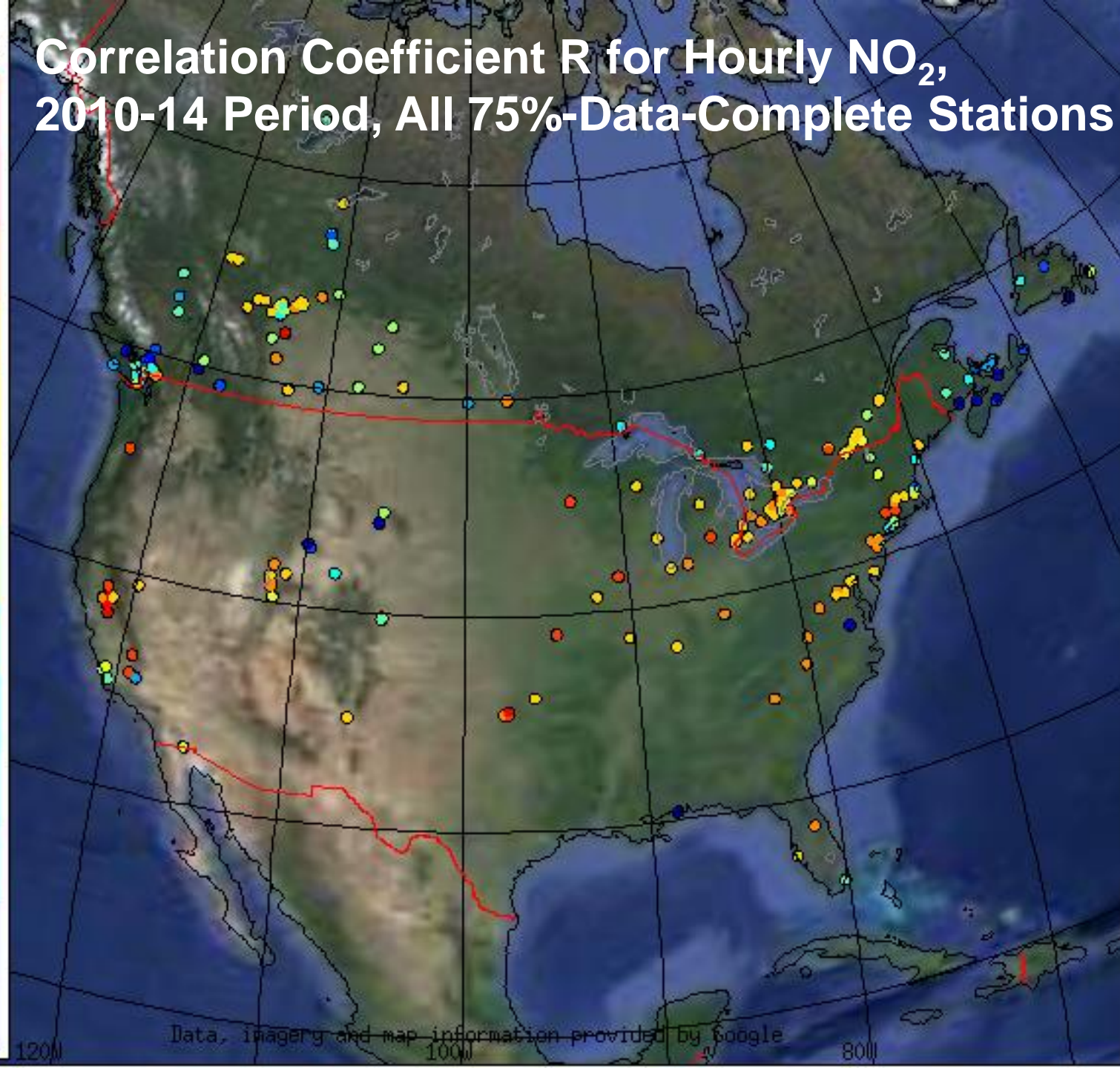
0.30

0.25

0.20

0.15

0.10



Data, imagery and map information provided by Google



PM<sub>2.5</sub> - R



# Correlation Coefficient R for Hourly PM<sub>2.5</sub>, 2010-14 Period, All 75%-Data-Complete Stations

0.65

0.60

0.50

0.45

0.40

0.35

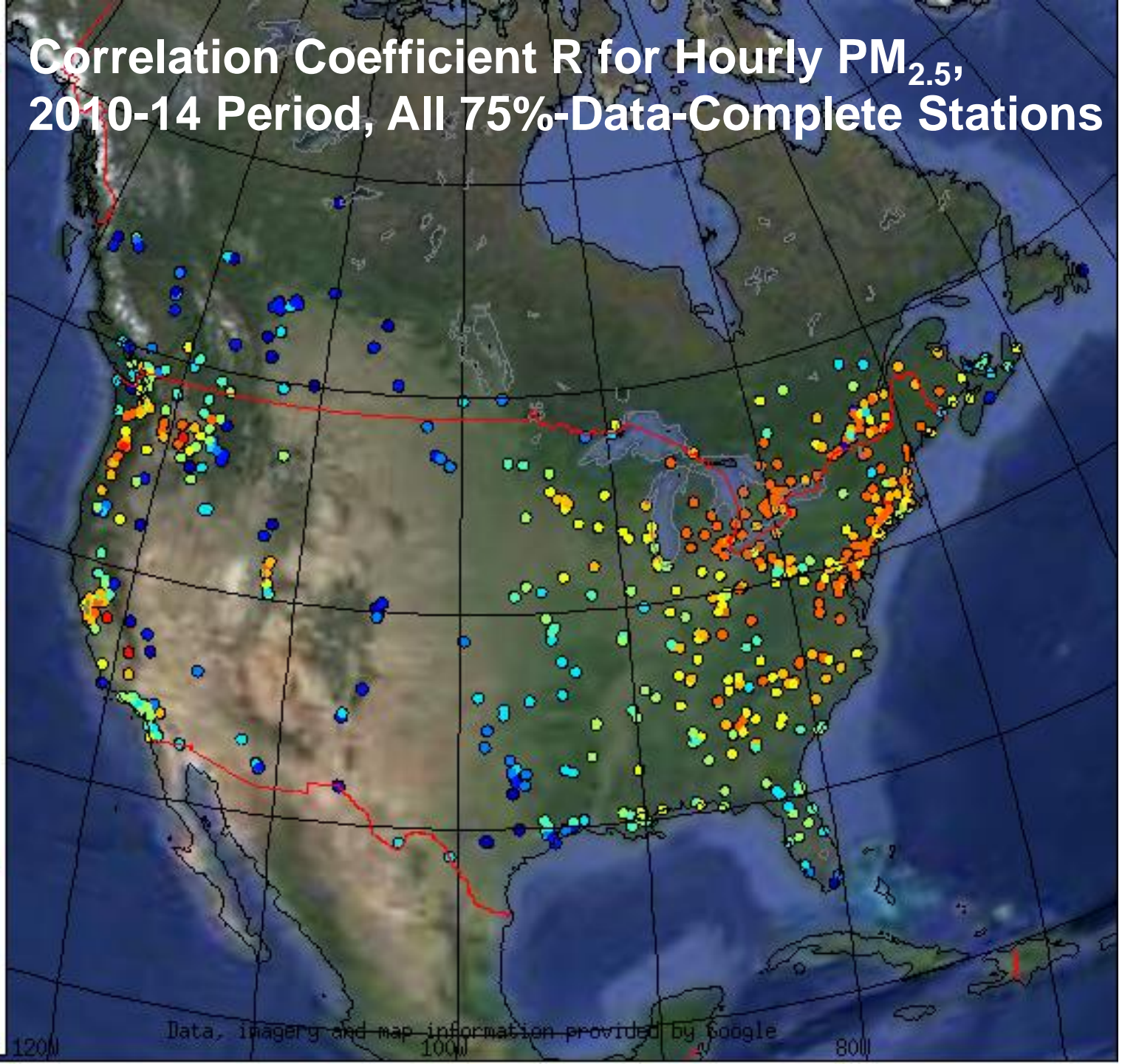
0.30

0.25

0.20

0.15

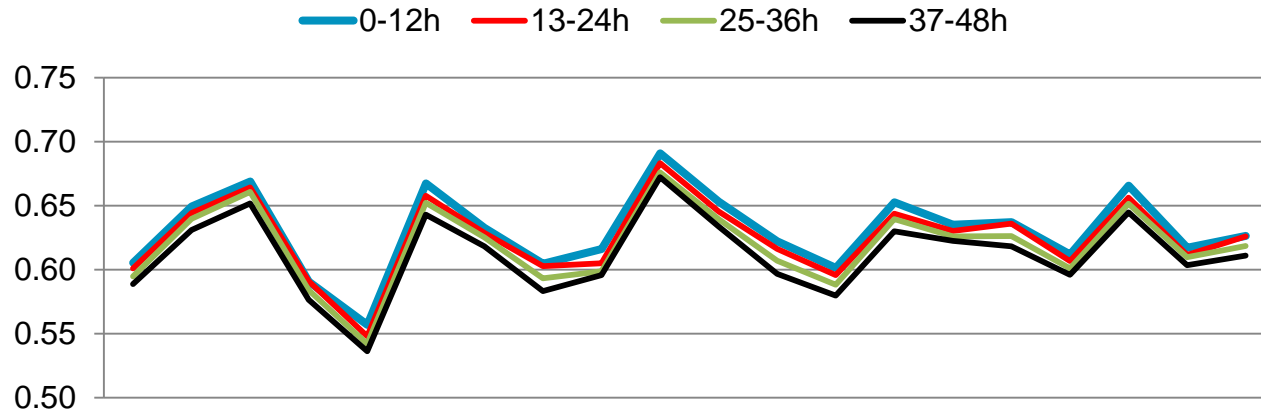
0.10



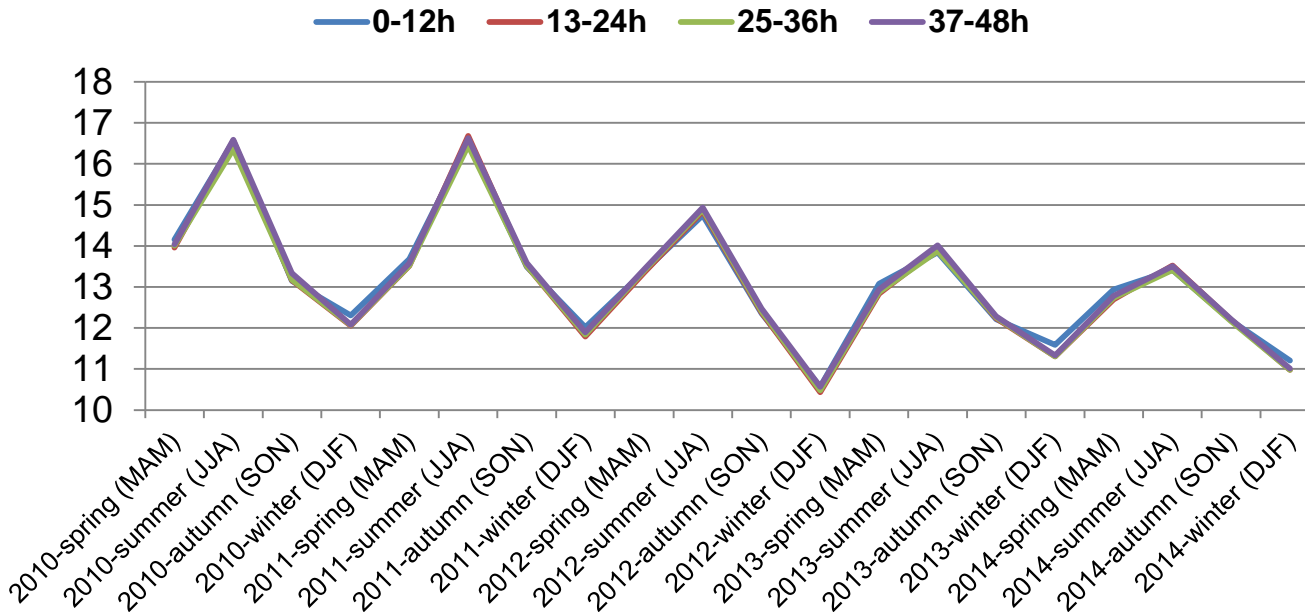
# Impact of Forecast Lead Time on Model Skill

## → First 12 Hours Have Best Scores on Average

### R - O<sub>3</sub> by Year and Season, 2010-2014

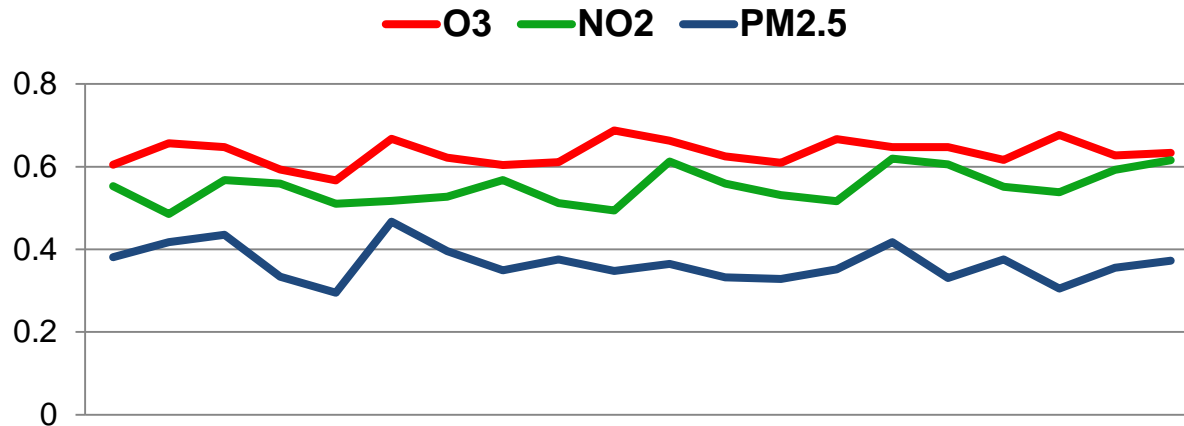


### RMSE - O<sub>3</sub> by Year and Season, 2010-2014

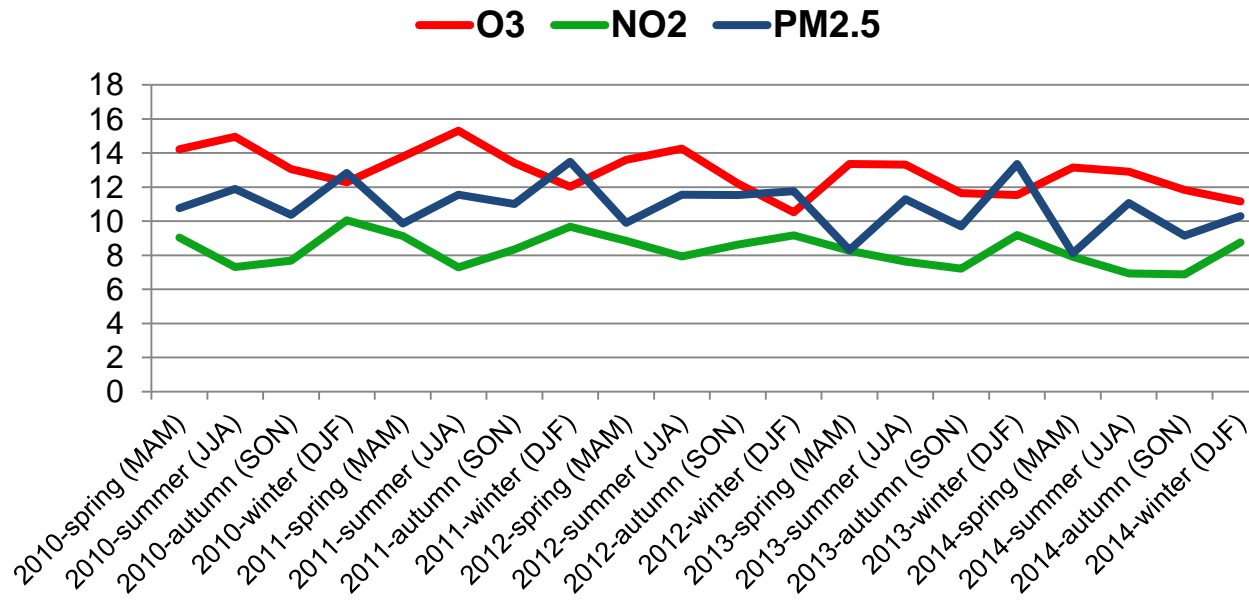


# Trends in Full-Domain Seasonal R and RMSE Scores over 2010-14 Period for 0-12 H Forecasts

## R - By Year and Season, 2010-2014

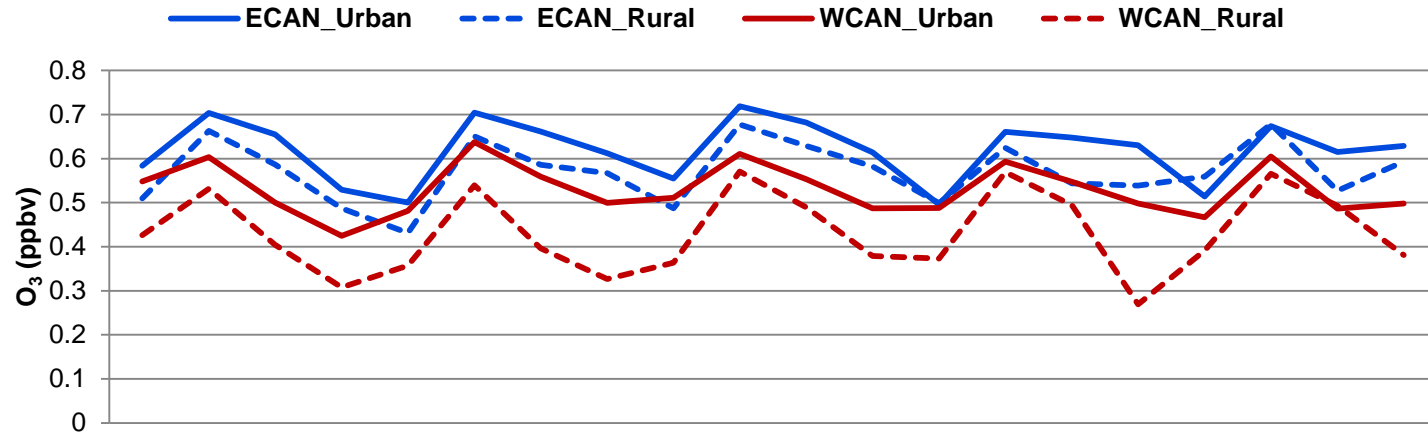


## RMSE - By Year and Season, 2010-2014

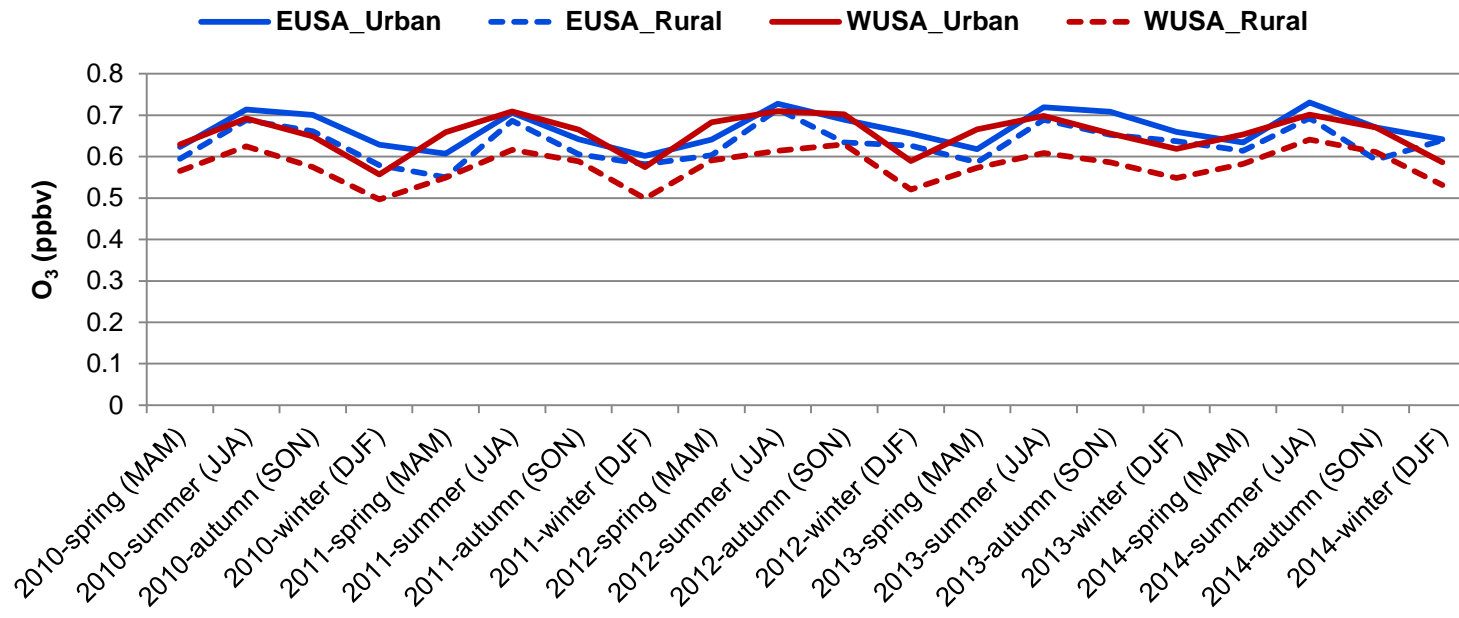


# Variation of Seasonal Correlation Coefficient R for O<sub>3</sub> by Region and Landuse, 2010-2014

## R - O<sub>3</sub> By Year, Season, and Canadian Region

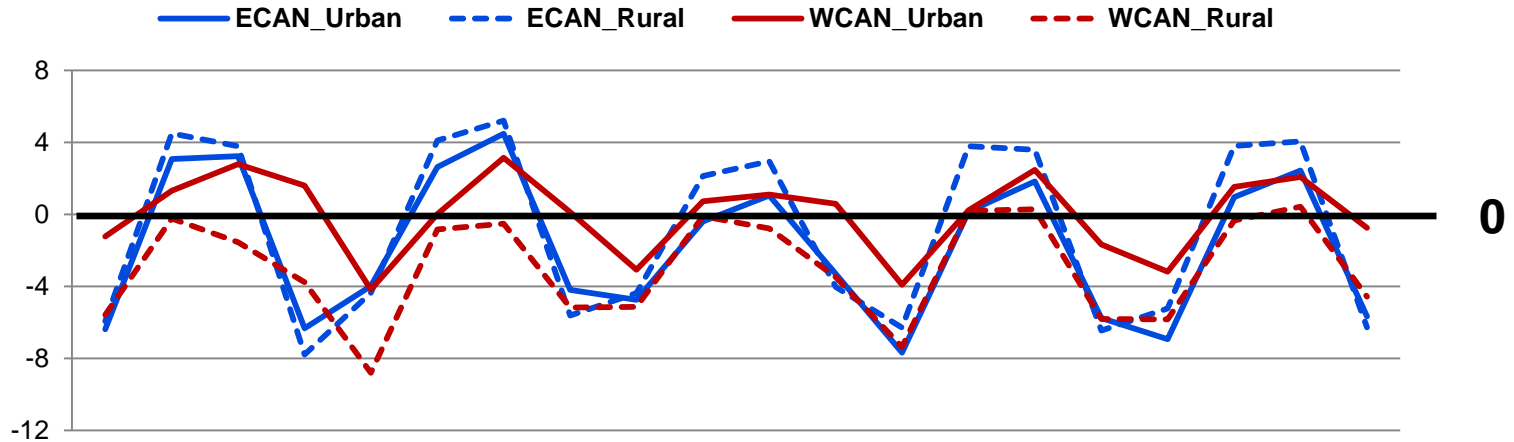


## R - O<sub>3</sub> By Year, Season, and U.S. Region

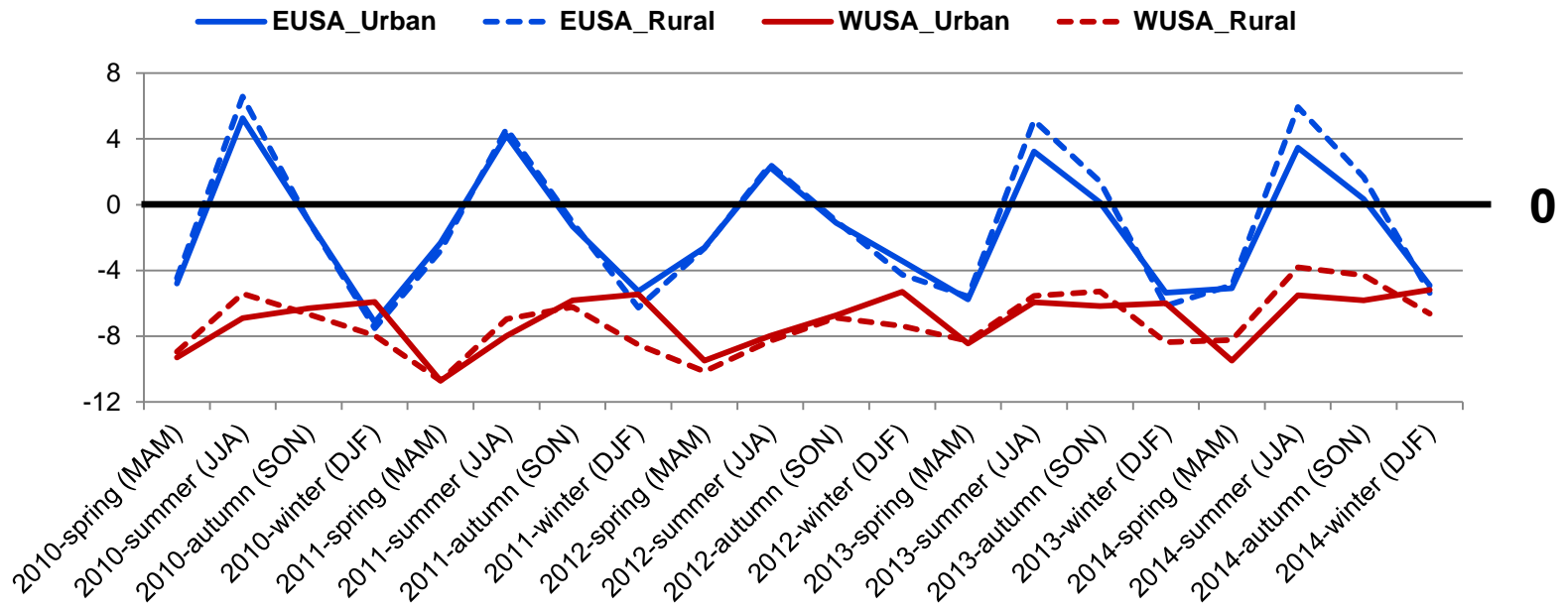


# Variation of Seasonal Mean Bias for O<sub>3</sub> by Region and Landuse, 2010-2014

## MB - O<sub>3</sub> By Year, Season, and Canadian Region



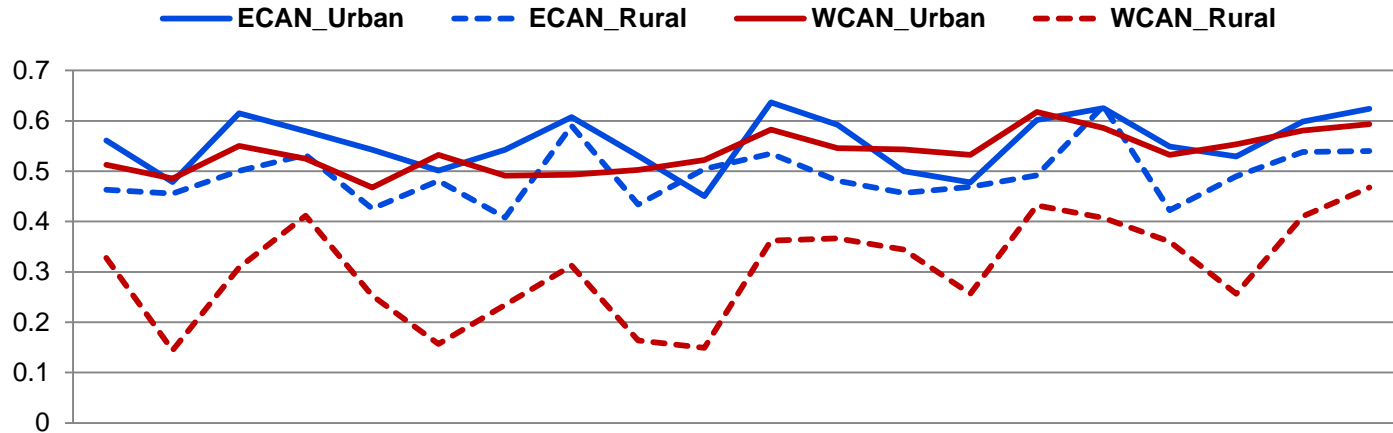
## MB - O<sub>3</sub> By Year, Season, and U.S. Region



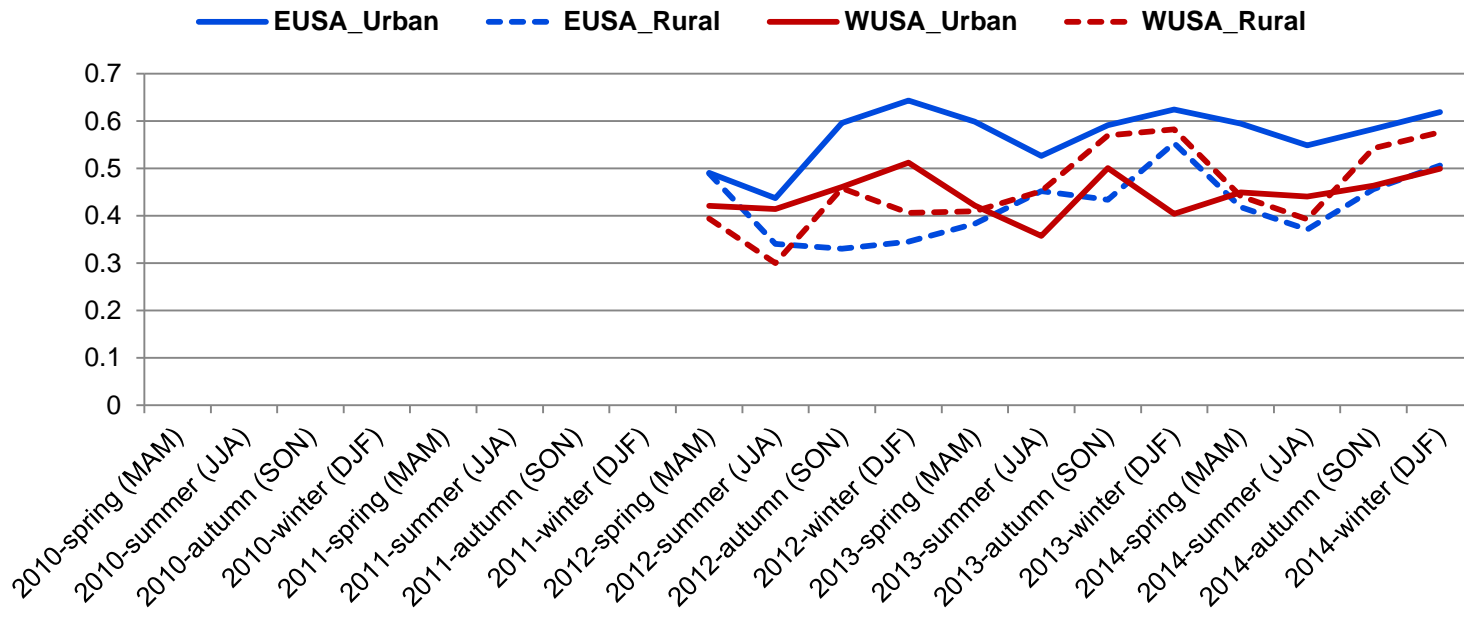


# Variation of Seasonal Correlation Coefficient R for NO<sub>2</sub> by Region and Landuse, 2010-2014

## R - NO<sub>2</sub> By Year, Season, and Canadian Region

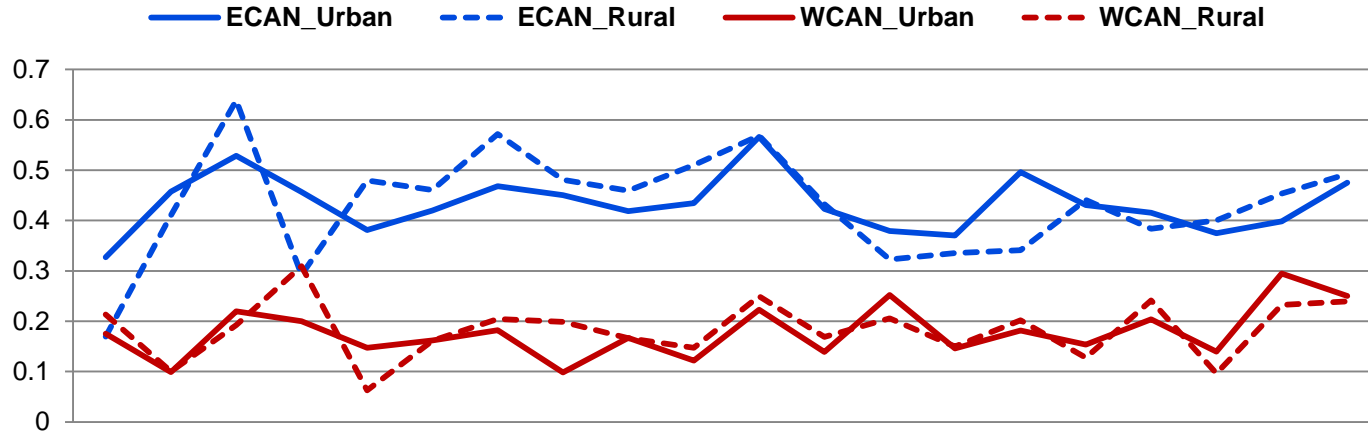


## R - NO<sub>2</sub> By Year, Season, and U.S. Region

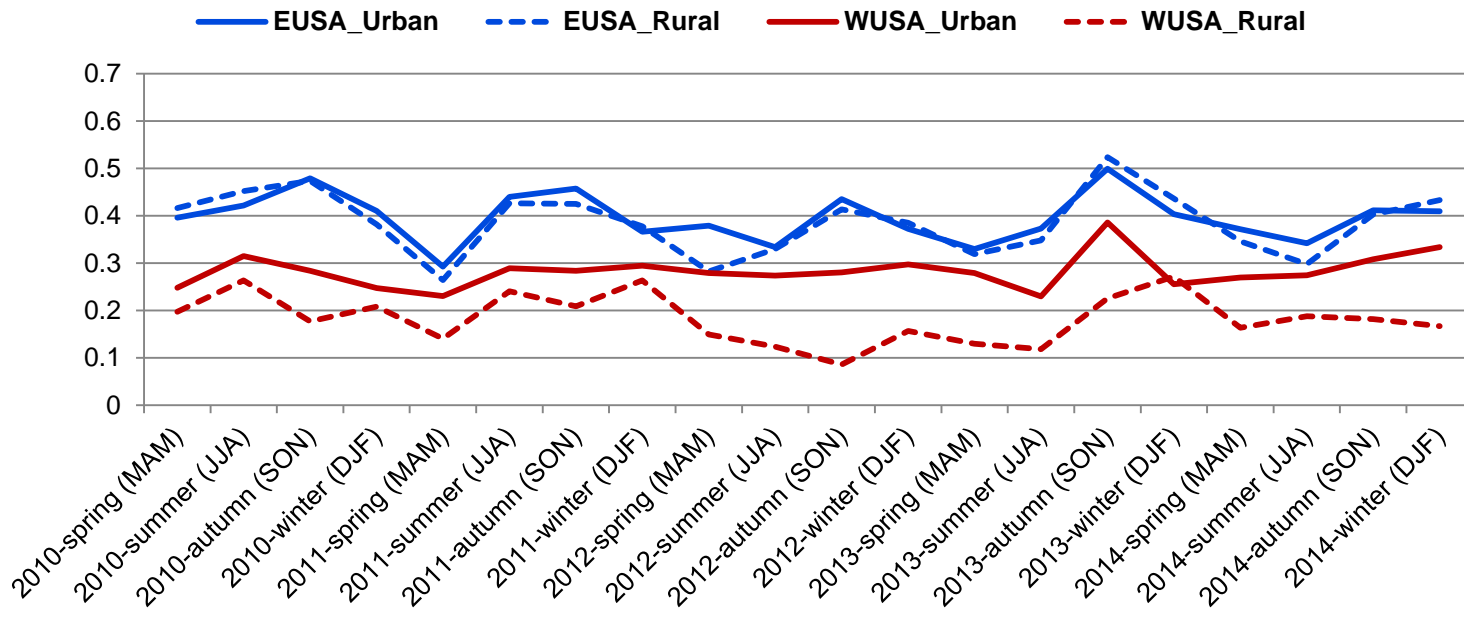


# Variation of Seasonal Correlation Coefficient R for PM<sub>2.5</sub> by Region and Landuse, 2010-2014

## R - PM<sub>2.5</sub> By Year, Season, and Canadian Region



## R - PM<sub>2.5</sub> By Year, Season, and U.S. Region



# Summary and Conclusions

- A 5-year performance evaluation has been carried out for the operational Canadian AQ forecast model GEM-MACH for the period 2010-2014
- GEM-MACH was updated 7 times during this period
- Near-real-time measurements of  $O_3$ ,  $NO_2$ , and  $PM_{2.5}$  were used for the evaluation after careful filtering; different sets of stations were chosen depending upon the data completeness criterion that was used
- A trend towards improved model performance can be discerned, especially for R and RMSE scores
- Regional differences and urban-rural differences are evident in all performance metrics



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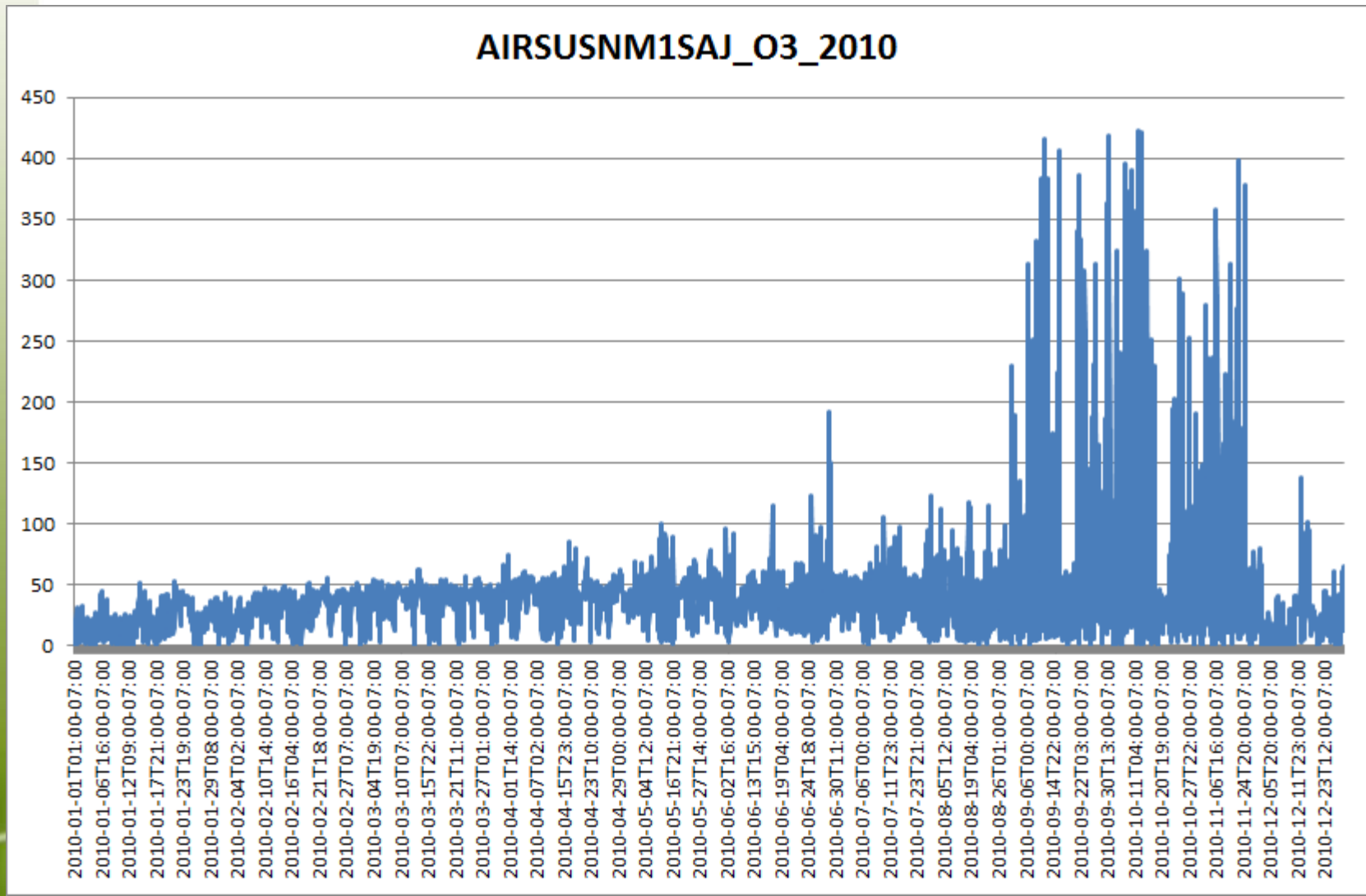
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# Thank you for your attention

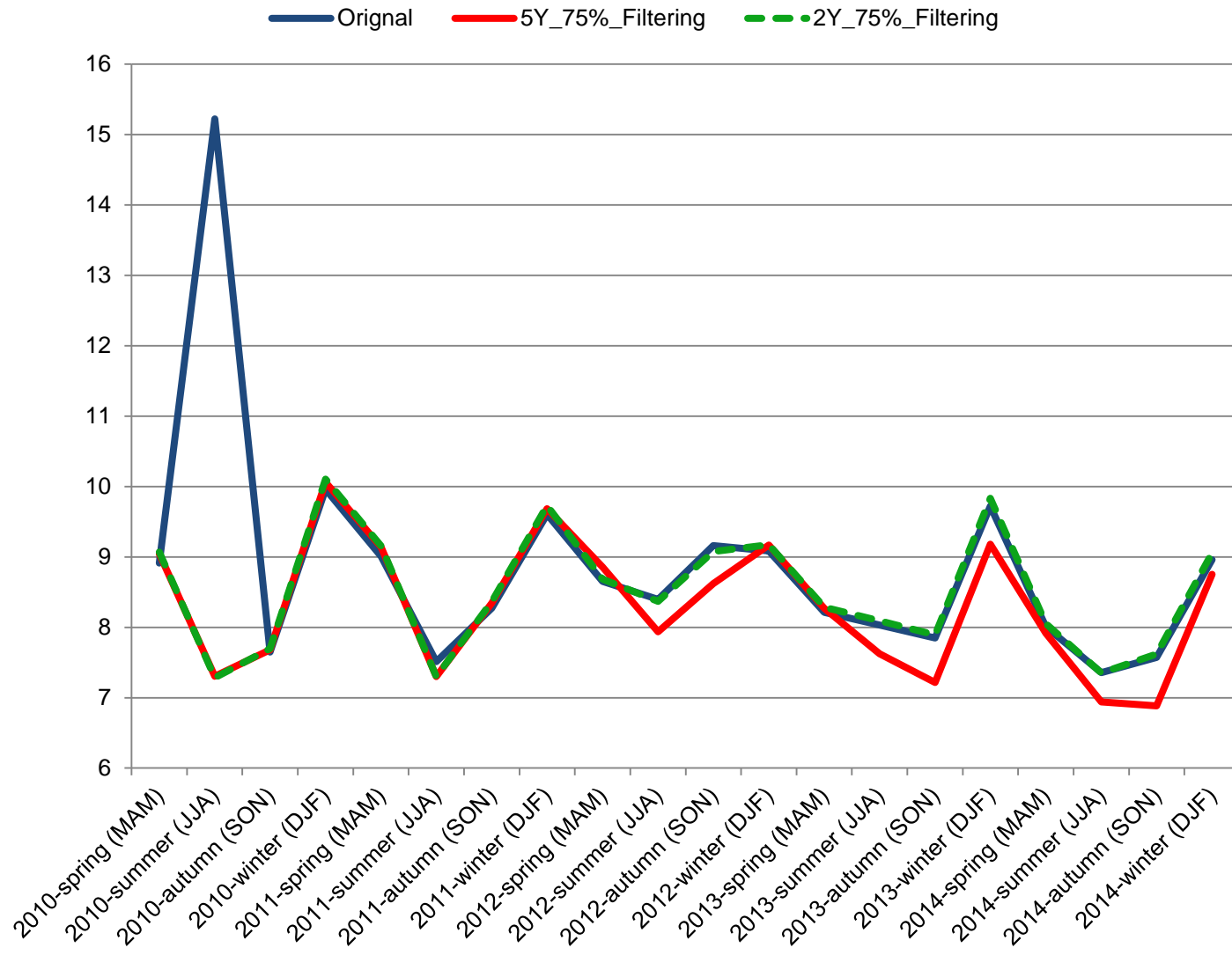


# 2010 O<sub>3</sub> Time Series, AQS Station in “Four Corners” Region of New Mexico

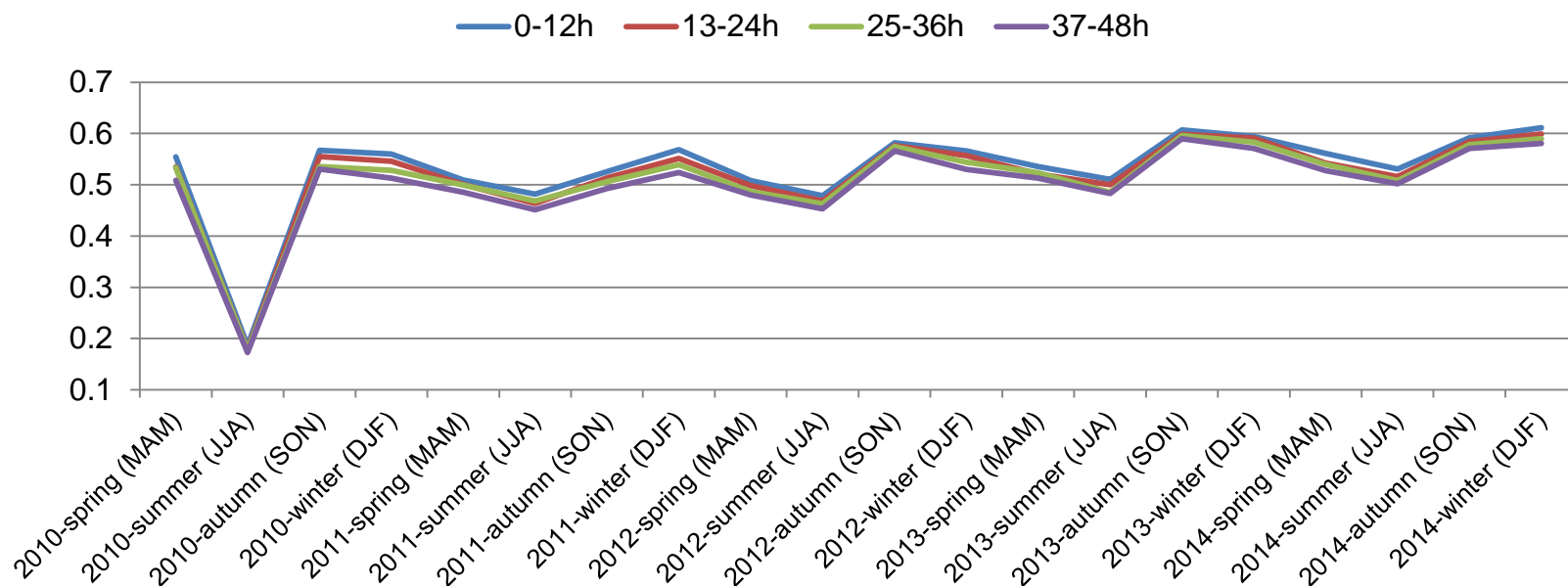


# Impact of Data Filtering on NO<sub>2</sub> Seasonal RMSE Scores, 2010-2014

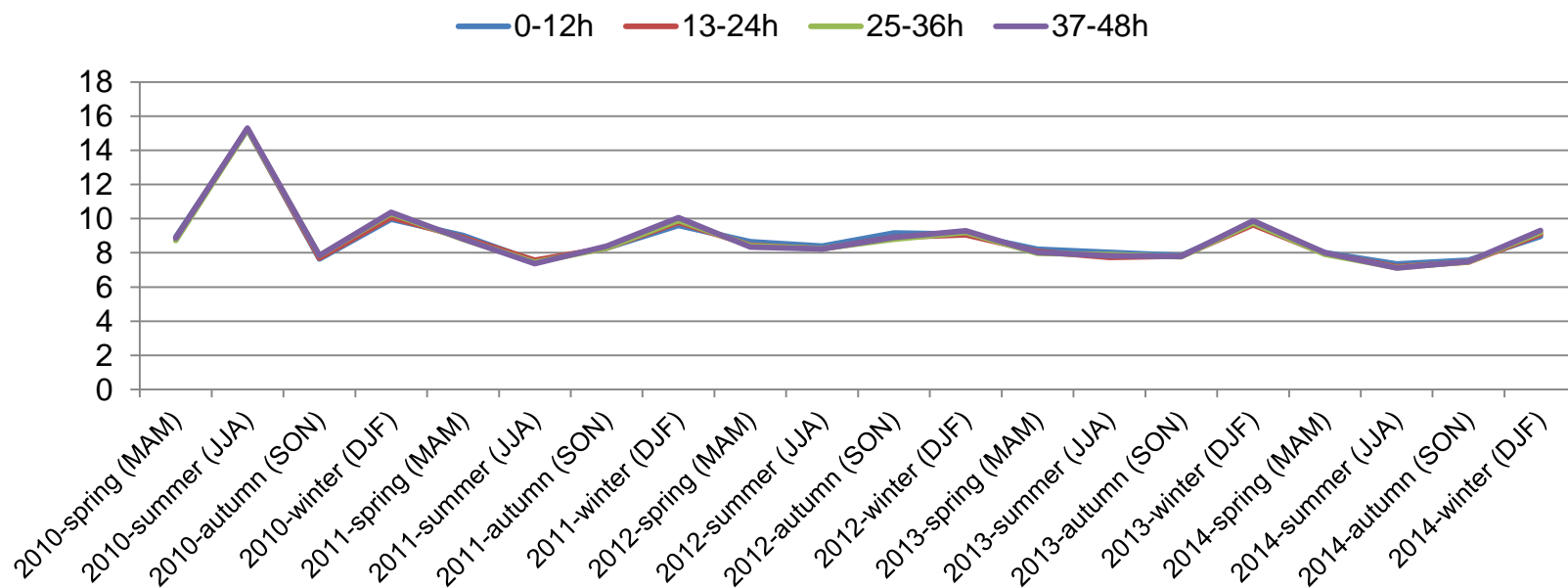
## RMSE -NO<sub>2</sub> by Year and Season, 2010-2014



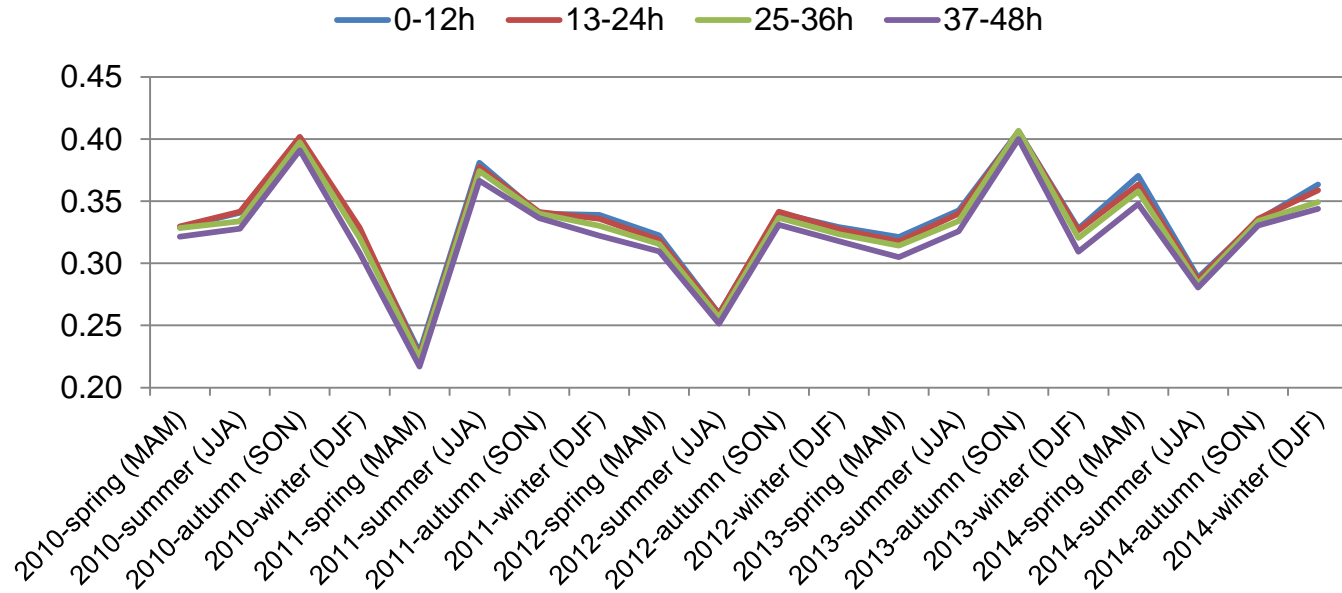
## R – NO2 by year and season



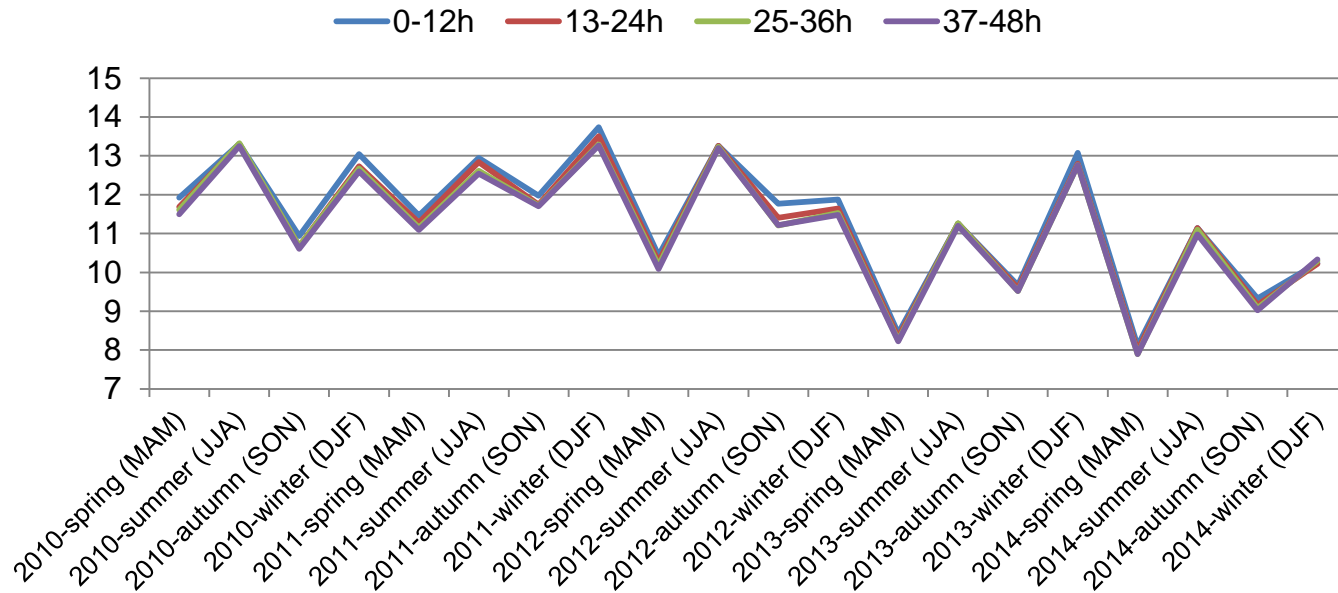
## RMSE – NO2 by year and season



## R - PM2.5 by year and season

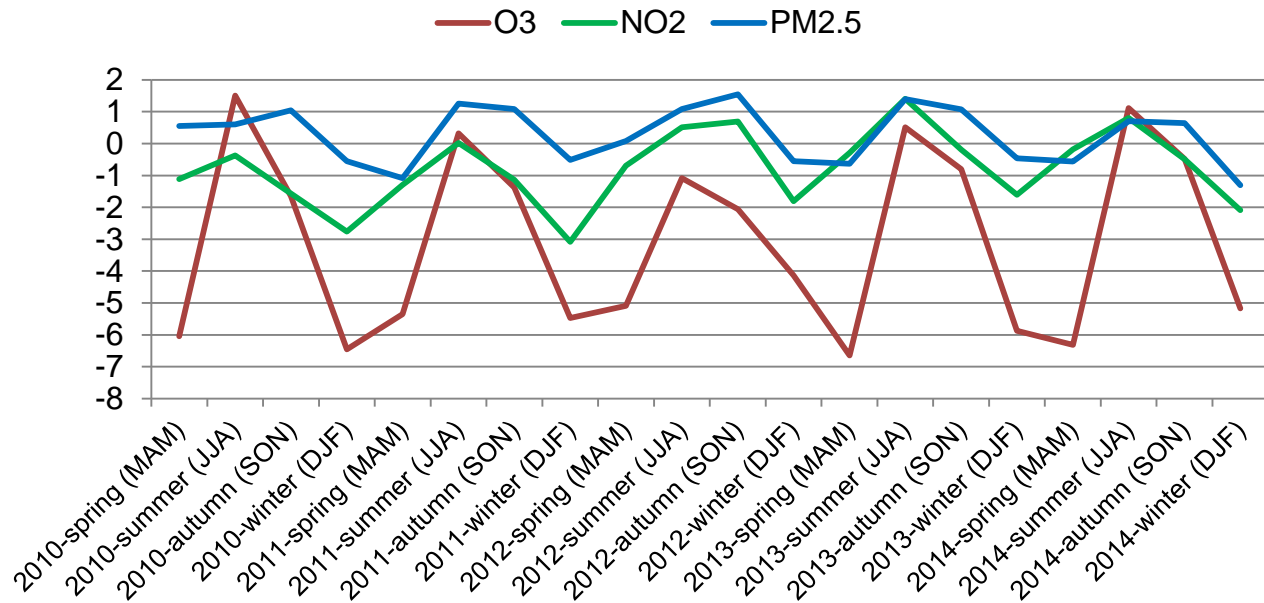


## RMSE - PM2.5 by year and season





## MB - by year and season



## NMB - by year and season

